SECTION 10—MANUFACTURING AND FABRICATION TECHNOLOGY

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OVERVIEW

This section describes technologies required for the production of military hardware. In most cases, the technologies, the equipment and the know-how are dual use and impact civil applications where cost, flexibility, competitiveness, etc., have become major concerns. In some cases, these technologies are not state of the art, and the United States is not the world leader in the technology. All countries engaged in the production of military weapons, munitions, and systems possess, to some degree, the know-how in the technology areas indicated in the box above. The level of the technology possessed by a country directly affects the level of military hardware that can be produced and the cost and reliability of the hardware. The concerns of the United States are no longer directed solely at the former technologically advanced Warsaw Pact countries but also at developing countries that are attempting to produce weapons of mass destruction. Therefore, the level of concern for machine tool technology necessary to meet the U.S. anti-proliferation goals is less than that for the state-of-the-art machine tools. Several different technologies, associated with a modern industrial base, are addressed in this section: many types of machine tools for advanced fabrication, production, and processing; certain nondestructive evaluation (NDE) and nondestructive inspection (NDI) equipment; bearings; and certain robots.

SECTION 10.1—ADVANCED FABRICATION AND PROCESSING

OVERVIEW

This subsection encompasses two groups of technologies. The first group includes equipment for fabricating structures of various advanced manufacturing techniques: spin, flow, and shear forming machines; superplastic forming/diffusion bonding; high-temperature furnaces and heaters; and stretch forming machines. These technologies involve such actions as bending and/or stretching finished material to form a desired shape or rolling material over mandrels to form curvilinear or cylindrical cross-section parts. The second group includes the development, refinement, and production of nonorganic coatings for nonelectronic substrates. Such substrates include metal, ceramics, various composites, and optical systems. The technologies cover all pertinent coating design features, such as coating formulation, substrate and source material preparation, and post-coating treatments. Of concern are coatings to (1) protect substrate materials from oxidation, hot corrosion, wear, erosion and fatigue; (2) reduce heat input to the substrate; or (3) modify the reflectance or transmittance of the substrate material. For information on related CAD/CAM technology see Section 8.2.

Table 10.1-1. Advanced Fabrication and Processing Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
SPIN, FLOW AND SHEAR FORMING MACHINES	Equipped with numerical or computer controls, containing > 2 axes contouring control and capable of applying a roller force > 60 kN.	None identified	None identified	None identified	WA IL Cat 2. NDUL 1.1 MTCR 3
SUPERPLASTIC FORMING/DIFFUSION BONDING (SPF/DB)	Capable of bonding certain alloys (primarily titanium, nickel, aluminum and titanium aluminides) in a single heat cycle.	None identified	None identified	None identified	WA IL Cat 2
VACUUM OR CONTROLLED ENVIRONMENT INDUCTION FURNACES	Diameter ≥ 600 mm inside the induction coil, Operating at > 850 °C using 0.5 kW power supplies	None identified	None identified	None identified	NDUL 1.4
VACUUM OR CONTROLLED ATMOSPHERE METALLURGICAL MELTING AND CASTING FURNACES	Arc melt and casting furnaces with consumable electrode capacities >1,000 cm^3 and < 20,000 cm^3 and operating at temp >1,700 °C. Electron beam melting and plasma atomization and melting furnaces with power ≥ 50 kW and temperature >1,200 °C	None identified	None identified	None identified	NDUL 1.8
CHEMICAL VAPOUR DEPOSITION (CVD) EQUIPMENT	High vacuum rotating seals (≤ 0.01 Pa) or *in situ* coating thickness control.	None identified	None identified	None identified	WA IL Cat 1, 2 MTCR 7
ION IMPLANTATION PRODUCTION EQUIPMENT	Beam current ≥ 5 mA	None identified	None identified	None identified	WA IL Cat 2
ION ASSISTED RESISTIVE HEATING VAPOUR DEPOSITION (ION PLATING) PRODUCTION EQUIPMENT	Vacuum of 10^{-3} torr, or better, A substrate to plasma potential of 15 to 20 V and An overall capability to deposit film with a uniformity of ± 1.0 percent over the substrate surface.	None identified	None identified	None identified	WA IL Cat 2

(Continued)

Table 10.1-1. Advanced Fabrication and Processing Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
PLASMA SPRAY EQUIPMENT	Either operation at reduced pressure controlled atmosphere (≤10 kPa measured above and within 300 mm of gun nozzle) in a vacuum chamber capable of 0.01 Pa; or Incorporating in situ coating thickness control.	None identified	None identified	None identified	WA IL Cat 2
SPUTTER DEPOSITION EQUIPMENT	Capable of current densities ≥ 0.1 mA/mm^2 at a deposition rate ≥ 15 μm/hr.	None identified	None identified	None identified	WA IL Cat 2
THERMAL SPRAY FORMING EQUIPMENT	Power levels > 150 kW, Gas velocities of 3,000 m/s and Spray rates of > 15 kg/h.	None identified	Digitally controlled atomization of molten metal and automatic rastering of mandrel	None identified	None
SPIN, FLOW AND SHEAR FORMING MACHINES	Equipped with numerical or computer controls, containing > 2 axes contouring control and capable of applying a roller force > 60 kN.	None identified	None identified	None identified	WA IL Cat 2. NDUL 1.1 MTCR 3
SUPERPLASTIC FORMING/DIFFUSION BONDING (SPF/DB)	Capable of bonding certain alloys (primarily titanium, nickel, aluminum and titanium aluminides) in a single heat cycle.	None identified	None identified	None identified	WA IL Cat 2
VACUUM OR CONTROLLED ENVIRONMENT INDUCTION FURNACES	Diameter ≥ 600 mm inside the induction coil, Operating at > 850 °C using 0.5 kW power supplies	None identified	None identified	None identified	NDUL 1.4
METROLOGY EQUIPMENT FOR SPECTRAL CHARACTERIZATION OF REFLECTANCE, TRANSMISSION, ABSORPTION AND SCATTER.	Capable of measuring reflectance/transmission to better than 1 part in 1,000 absolute accuracy or Absorption/scatter to better than 1 part in 100,000.	None identified	None identified	None identified	None
SINGLE CRYSTAL ALLOY CASTING EQUIPMENT	Capable of producing cooled turbine blades with stress rupture life exceeding 400 hours at 1273 K (1,000 °C) at a stress of 200 MPa	None identified	None identified	None identified	WA IL Cat 9
COMPOSITE FILAMENT WINDING EQUIPMENT	Three or more coordinated axes.	None identified	None identified	None identified	WA IL Cat 1 MTCR 6
COMPOSITE TAPE LAYING EQUIPMENT	Two or more coordinated axes.	None identified	None identified	None identified	WA IL Cat 1 MTCR 6
COMPOSITE WEAVING OR INTERLACING EQUIPMENT	Ability to perform multi-directional and multi-dimensional weaving or interlacing.	None identified	None identified	None identified	WA IL Cat 1 MTCR 6
EQUIPMENT FOR PRODUCING PREPEGS BY THE HOT MELT METHOD	Ability to manufacture prepegs with a specific tensile strength > 17 × 10^4 m and A specific modulus > 10 × 10^6 m or A melting, softening or sublimation point >1,922 K (1,649 °C).	None identified	None identified	None identified	WA IL Cat 1

(Continued)

Table 10.1-1. Advanced Fabrication and Processing Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
EQUIPMENT TO MANUFACTURE FIBERS	Capable of converting polymeric fibers (such as polyacrylonitrile, rayon, pitch, or polycarbosilane) into carbon fibers or silicon carbide fibers.	None identified	None identified	None identified	WA IL Cat 1
SYSTEMS SPECIALLY DESIGNED TO PREVENT CONTAMINATION IN THE PRODUCTION OF METAL ALLOYS AND METAL POWDERS.	Capable of maintaining a contamination level < 3 non-metallic particles larger than 100 microns in 10^9 alloy particles (for nickel).	None identified	None identified	None identified	WA IL Cat 1
EQUIPMENT FOR THE MANUFACTURE OF MICROMECHANICAL DEVICES, INCLUDING LITHOGRAPHY EQUIPMENT, ELECTRON AND ION BEAM MILLING-ETCHING-GRINDING-POLISHING MACHINES, CHEMICAL VAPOUR DEPOSITION AND ETCHING EQUIPMENT.	Ability to manufacture micromechanical devices with dimensions ≤1 micron.	None identified	Material removal and assembly equipment including lithography, electron and ion beam milling, grinding, etching, polishing, chemical vapor deposition and etching; and tooling and fixturing	None identified	WA IL Cat 2., 3
DEEP HOLE DRILLING MACHINES	Computer controlled and having a maximum depth-of-bore > 5,000 mm.	None identified	None identified	None identified	WA IL Cat 2
CHEMICAL VAPOUR DEPOSITION (CVD)	High vacuum rotating seals (≤ 0.01 Pa) or In situ coating thickness control.	None identified	None identified	None identified	WA IL Cat 2 MTCR 7
ION IMPLANTATION PRODUCTION	Beam current ≥ 5 ma	None identified	None identified	None identified	WA IL Cat 2
ION ASSISTED RESISTIVE HEATING VAPOUR DEPOSITION (ION PLATING) PRODUCTION	Vacuum of 10^{-7} torr, or better, An ion source acceleration voltage of 5 to 40 kV, and A current density of > 30 mA.	None identified	None identified	None identified	WA IL Cat 2
PLASMA SPRAY	Operation at reduced pressure controlled atmosphere (≤ 10 kPa) in a vacuum chamber capable of 0.01 Pa; or Incorporating in situ coating thickness control.	None identified	None identified	None identified	WA IL Cat 2
SPUTTER DEPOSITION	Capable of current densities ≥ 0.1 mA/mm^3 at a deposition rate ≥ 15 μm/hr.	None identified	None identified	None identified	WA IL Cat 2
PYROLYTIC DEPOSITION	Ability to produce pyrolytically derived materials (e.g., pyrolytic graphite), from precursor gases which decompose in the 1300° to 2900 °C range, at pressures of 1 mm Hg to 150 mmHg.	None identified	None identified	None identified	MTCR 7
HIGH TEMPERATURE PROTECTION COATINGS FOR ENGINE PARTS	Reduce temperature of underlying layer by 150° C, or greater.	ZrO2 + Y2O2	None identified	None identified	WA IL Cat 2

(Continued)

Table 10.1-1. Advanced Fabrication and Processing Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
HIGH TEMPERATURE PROTECTION COATINGS FOR ENGINE PARTS	Allow operation at 2,000 °C.	Silicides	None identified	None identified	WA IL Cat 2
HIGH TEMPERATURE PROTECTION COATINGS FOR ENGINE PARTS	Allow operation at 2,000 °C and resists erosion.	Ceramics; e.g. alumina and magnesia	None identified	None identified	WA IL Cat 2
INCREASED WEAR COATINGS FOR ENGINES, DOMES AND WINDOWS	Hardness ≥ 9,000 kg/mm^2	Cr	None identified	None identified	WA IL Cat 2
INCREASED WEAR COATINGS FOR BEARINGS	Increase of 300% in surface hardness, with concurrent reduction in sliding friction by a factor of 3.	AU, Pt, Ir, Ta, C, N2 and B	None identified	None identified	WA IL Cat 2
OPTICAL COATINGS FOR GUIDANCE SYSTEMS	Anti-reflection films and resists rain, sand and oxidation at temperatures > 700 °C.	IR coatings; e.g., SnS and ZnSe	None identified	None identified	WA IL Cat 2
OPTICAL COATINGS FOR SENSORS	Filters, with selectable or variable bandpass in 0.2 to 20 micron spectral range.	Oxides, fluorides and sulfides	None identified	None identified	WA IL Cat 2
STEALTH COATINGS FOR SIGNATURE REDUCTION	Signature reduction	Polymers and organic matrix composites	None identified	None identified	WA IL Cat 2

SECTION 10.2—BEARINGS

OVERVIEW

This subsection covers various types of bearings and the technology required for their development and manufacture. Bearing types have proliferated as the applications for their use have developed, particularly in advanced machines where the relative motion between two parts must occur smoothly, quietly, and reliably and with a long time between failures. In general, bearings can be categorized as either sliding surface, rolling element, or magnetic. Sliding bearings may incorporate self-lubricating materials or introduce a lubricant between the moving parts. When load capacity is obtained because of the dynamic motion within the bearing, it is known as a hydrodynamic bearing. Rolling bearings, however, may use either balls, cylindrical rollers, tapered rollers, spherical rollers, or needle roller elements. The lubricant, bearing design, materials, and operating environment are usually important parameters in the development of a thin lubricant film between the rolling elements and the mating surfaces within the bearing. Magnetic bearings are manufactured using magnetic materials and operate in a mode in which the surfaces do not physically slide or roll on each other but are separated by the strength of the magnetic field.

Bearings addressed in this subsection include the following types:

- Sliding bearings - fluid film, gas film, and fabric-lined
- Rolling element bearings - precision, hostile environment element anti-friction, low-torque anti-friction, and extreme precision
- Magnetic bearings - active.

Table 10.2-1. Bearings Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
BEARING, BALL OR SOLID ROLLER, EXCEPT TAPERED.	Manufactured for use in a radioactive environment at temperatures > 300 °C either by use of special materials or by special heat treatment.	Tungsten carbide, synthetic sapphire, Monel, beryllium, M50 NiL steel, Stellite, Inconel, beryllium copper or silicon nitride.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy.	None identified	WA IL Cat 2
BEARING, BALL OR SOLID ROLLER, EXCEPT TAPERED.	Having lubrication elements or modifications that enable operation at speeds > 2.3 million DN.	Tungsten carbide, synthetic sapphire, Monel, beryllium, M50 NiL steel, Stellite, Inconel, beryllium copper or silicon nitride.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy.	None identified	WA IL Cat 2

(Continued)

Table 10.2-1. Bearings Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
BEARING, BALL OR SOLID ROLLER, EXCEPT TAPERED.	For 0.5 inch-pitch-diameter bearings with 5×10^{-4} radial play, operate at slow speed (1–4 RPM) 400 gram thrust load friction torque < 0.6 gm cm; For other sizes, loads or clearances, a starting torque < 4,500 milligm-mm.	Tungsten carbide, synthetic sapphire, Monel, beryllium, M50 NiL steel, Stellite, Inconel, beryllium copper or silicon nitride.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy.	None identified	WA IL Cat 2
BEARINGS, PRECISION BALL	Having tolerances of ABEC 9. ABEC 9P, ISO Standard Class 2 or 2A, or better.	Tungsten carbide, synthetic sapphire, Monel, beryllium, M50 NiL steel, Stellite, Inconel, beryllium copper or silicon nitride.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy.	None identified	WA IL Cat 2
BEARINGS, SOLID TAPERED ROLLER	Having tolerances of ANSI/AFBMA/ISO Class 0 inch or ANSI/AFBMA Class B/ISO Class 4, or better, with lubrication elements allowing speeds > 2.3 million DN and a fracture toughness of 45 ksi square root inches.	Manufactured from M50 NiL steel, or silicon nitride, with lubrication elements allowing speeds > 2.3 million DN.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy.	None identified	None
BEARINGS, SOLID TAPERED ROLLER	Having tolerances of ANSI/AFBMA/ISO Class 0 inch or ANSI/AFBMA Class B/ISO Class 4, or better, for operation at temperatures < – 54 °C or > 150 °C and having a fracture toughness of 45 ksi square root inches.	M50 NiL steel, or silicon nitride, for operation at temperatures < – 54 °C or > 150 °C.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy.	None identified	None
BEARINGS, NEEDLE ROLLER	Having a fracture toughness of 45 ksi square root inches.	M50 NiL steel.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy	None identified	None
BEARINGS, GAS-LUBRICATED FOIL	Operation at temperatures > 288 °C and a unit load capacity > 15 psi (0–1 MPa) and, In machine tools, permits runouts of 0.0004 mm (about 1/2 that of precision rolling bearings).	Gas; e.g., helium.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy	None identified	None

(Continued)

Table 10.2-1. Bearings Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
BEARINGS, ACTIVE MAGNETIC	Having flux densities of 2.0 teslas, or greater, and Yield strengths > 414 MPa.	High-saturation flux-density magnetic materials; e.g., Vanadium Permandur, Hiperco 27.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy	None identified	WA IL Cat 2
BEARINGS, ACTIVE MAGNETIC	Having all electromagnetic 3D homopolar bias designs for actuators	Magnetic materials with load carrying capacities > 70 psi and rare-earth high density materials.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy	None identified	WA IL Cat 2
BEARINGS, ACTIVE MAGNETIC	Having position sensors capable of operation at temperatures > 177 °C.	Magnetic materials with load carrying capacities > 70 psi and rare-earth high density materials.	Grinding, lapping and honing machines and fixtures; gaging and metrology equipment for curved geometry measurement to 1 μ inch accuracy	None identified	WA IL Cat 2

SECTION 10.3—METROLOGY

OVERVIEW

This subsection covers technology for dimensional measuring systems and equipment needed for precise determination of the dimensions of manufactured parts, machine tools, and inspection machines. Included are systems for in-process measurement and post-manufacture inspection. This technology area is of paramount importance for the construction of systems incorporating mechanical or electrical components built to exacting tolerances, whether such hardware is military or civil. This technology is highly dependent on sensors, positioners, feedback systems, digital computers, and associated components and hardware. Included in the list of metrology equipment are coordinate, linear and angular measurement machines using laser, standard light, photogrammetry, and noncontact techniques. The tolerances of parts measured range from ±1 nm (corresponding to an optical surface finish prepared by diamond turning, with ion beam polishing) to ±10 μm (corresponding to more traditional metal machining).

Table 10.3-1. Metrology Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
COMPUTER, NUMERICALLY OR STORED PROGRAM CONTROLLED DIMENSIONAL INSPECTION MACHINES	Computer controlled coordinate-measuring machine (CMM) with both: ≥ 2 axes; and a one dimensional length measurement uncertainty ≤ (1.25 + L/1,000) μm, tested with a probe with an accuracy of < 0.2 μm (L is the measured length in mm).	None identified	Laser interferometer measuring equipment with accuracies < 1 μm	None identified	WA IL Cat 2 NDUL 1.3
LINEAR DISPLACEMENT (NON-CONTACT) MEASURING DEVICES	Non-contact type with a resolution ≤ 0.2 μm within a measuring range of 0.2 mm.	None identified	None identified	None identified	WA IL Cat 2 NDUL 1.3
LINEAR MEASURING MACHINES USING LINEAR VOLTAGE DIFFERENTIAL TRANSFORMER SYSTEMS	Linearity ≤ 0.1% within a measuring range up to 5 mm; and Drift ≤ 0.1% per day at a standard ambient room temperature ± 1 K.	None identified	None identified	None identified	WA IL Cat 2 NDUL 1.3
LINEAR MEASURING MACHINES	Laser, and The capability to maintain, for at least 12 hours, over a temperature range of ± 1 K around a standard temperature and pressure, both A resolution ≤ 0.1 μm over full scale and A measurement uncertainty ≤ (0.2 μm + L/2000 μm).	None identified	None identified	None identified	WA IL Cat 2 NDUL 1.3
ANGULAR DISPLACEMENT MEASURING DEVICES	Angular position deviation ≤ 0.00025°.	None identified	None identified	None identified	WA IL Cat 2 NDUL 1.3

(Continued)

Table 10.3-1. Metrology Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
METROLOGY EQUIPMENT FOR SPECTRAL CHARACTERIZATION OF REFLECTANCE, TRANSMISSION, ABSORPTION AND SCATTER	Capable of measuring reflectance/transmission to better than 50 ppm absolute accuracy or Absorption/scatter to better than 10 ppm.	None identified	None identified	None identified	WA IL Cat 2 MTCR 9
LASER LOCATION SYSTEMS	Automated, laser measuring system that uses optical triangulation to achieve high accuracy of 3 dimensional positions, with The capability to measure ≥ 10 points per second.	None identified	None identified	None identified	None
NON-CONTACT PROBE MEASUREMENT EQUIPMENT	5 Angstroms (5×10^{-8} cm) accuracy	None identified	None identified	None identified	MTCR 9
SOLID MODEL FITTING TECHNIQUE	An advanced means to evaluate conformance to design. Utilize randomly measured points described by three-dimensional standard coordinates, adjusts for misalignment of model, and reports deviations.	None identified	Machine tools, very accurate bearings and races, and laser measuring equipment	Solid model fitting software	None

SECTION 10.4—NON-DESTRUCTIVE INSPECTION EQUIPMENT

OVERVIEW

This subsection covers technologies for the non-destructive detection and characterization of flaws, such as cracks, porosity, inclusions, and delaminations, and for the non-destructive measurement or prediction of mechanical properties, such as bond strength or elastic moduli in materials, components, or structures. The technologies also involve the means for interpreting the significance of detected flaws so that an immediate accept/reject decision can be made or incremental changes can be made to correct a flawed or out-of-control process. In many instances, they provide the basis for the design and the determination of reliability and maintenance requirements for military systems, including ordnance, vehicles, ships, submarines, aircraft, and missiles.

Table 10.4-1. Non-Destructive Inspection Equipment Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
NON-DESTRUCTIVE INSPECTION SYSTEMS CAPABLE OF ADAPTIVE MOTION CONTROL FOR SCANNING COMPONENTS WHOSE NOMINAL ENVELOPE MAY VARY.	≥ 2 axes with adaptive control, allowing feedback action and equipped with sensors to allow examination of item to be inspected.	None identified	None identified	Special algorithms to control inspection	None
NON-DESTRUCTIVE INSPECTION SYSTEMS IN MORE THAN 4 INTERPOLATING AXES WHICH CAN BE COORDINATED SIMULTANEOUSLY FOR CONTOURING CONTROL	> 4 interpolating axes that can be coordinated simultaneously for contouring control	None identified	None identified	None identified	None
COMPUTER-BASED AUTOMATIC INSPECTION EQUIPMENT HAVING DEDICATED CIRCUITRY, HARDWARE AND SOFTWARE FOR AUTOMATIC COLLECTION, REDUCTION, ANALYSIS AND ACCEPT/REJECT CRITERIA, AND CAPABLE OF PROCESSING DATA IN REAL TIME.	Complete hardware/software system to allow control of equipment, as well as performing complete data collection, reduction and analysis, whether in real-time or near real-time.	None identified	None identified	None identified	None

SECTION 10.5—PRODUCTION EQUIPMENT

OVERVIEW

This subsection addresses machine tools used for the production of military systems and components. The individual machine tools provide the foundation of a manufacturing base. The equipment includes both numerically controlled (NC) and non-NC machines. NC machines are computer controlled so that the motions of the various axes are simultaneously and continually coordinated to maintain a predetermined (programmed) path. This machinery includes turning, milling, and grinding machines, electrical discharge machines (EDM); water and liquid jet machines; and electron beam and laser cutting machines. The non-NC machines include single point diamond cutting and fly-cutting machine tools. Such tools have wide application in the production of optical-quality surfaces.

Table 10.5-1. Production Equipment Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
MILLING MACHINE FOR REMOVING OR CUTTING METALS, CERAMICS OR COMPOSITES	More than 4 axes which have simultaneous contouring control, including rotary axes.	None identified	None identified	None identified	WA IL Cat 2 NDUL 1.2
MACHINE TOOLS FOR REMOVING OR CUTTING METALS, CERAMICS OR COMPOSITES BY TURNING, GRINDING OR MILLING	Two or more axes which have simultaneous contouring control and either Tilting spindles, Camming > 0.2 μm, Run-out < 0.2 μm, or Positioning accuracy on any rotary axis < 0.001°	None identified	None identified	None identified	None
GRINDING MACHINE FOR REMOVING OR CUTTING METALS, CERAMICS OR COMPOSITES	Two or more axes which have simultaneous contouring control and A positioning accuracy < 4 μm.	None identified	None identified	None identified	WA IL Cat 2
MACHINE TOOLS FOR REMOVING OR CUTTING METALS, CERAMICS OR COMPOSITES BY TURNING OR MILLING	Two or more axes which have simultaneous contouring control and A positioning accuracy < 6 μm.	None identified	None identified	None identified	WA IL Cat 2
ELECTRO DISCHARGE MACHINES (EDM) OF WIRE-FEED TYPE	Five or more axes for contour control	None identified	None identified	None identified	None
ELECTRO DISCHARGE MACHINES (EDM) OF NONWIRE TYPE	Two or more rotary axes for contour control	None identified	None identified	None identified	WA IL Cat 2 NDUL 1.2
MACHINE TOOLS FOR REMOVING METALS, CERAMICS OR COMPOSITES, BY MEANS OF WATER, OTHER LIQUID JETS, ELECTRON BEAM OR LASER BEAM.	Two or more rotary axes, that can be coordinated simultaneously, and A positioning accuracy of better than 0.003°	None identified	None identified	None identified	WA IL Cat 2

(Continued)

Table 10.5-1. Production Equipment Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
SPINDLE ASSEMBLIES, CONSISTING OF SPINDLES AND BEARINGS AS A MINIMAL ASSEMBLY, SPECIALLY DESIGNED FOR MACHINE TOOLS DESCRIBED ABOVE.	Run-out or camming < 0.0006 mm (0.6 μm) in one revolution of the spindle.	None identified	None identified	None identified	WA IL Cat 2
LINEAR POSITION FEEDBACK UNITS (E.G., INDUCTIVE TYPE DEVICES, GRADUATED SCALES, OR LASER SYSTEMS).	An overall accuracy < [(800 + (600 × L × 10^{-3})] nm, where L is the effective length in mm.	None identified	None identified	None identified	WA IL Cat 2
ROTARY POSITION FEEDBACK UNITS (E.G., INDUCTIVE TYPE DEVICES, GRADUATED SCALES, OR LASER SYSTEMS).	An accuracy < 0.00025°.	None identified	None identified	None identified	WA IL Cat 2
SLIDE WAY ASSEMBLIES CONSISTING OF A MINIMAL ASSEMBLY OF WAYS, BED AND SLIDE.	Yaw, pitch or roll < 2 sec. of arc TIR total indicator reading; horizontal straightness < 2 μm/300 mm length; and vertical straightness < 2 μm/300 mm length.	None identified	None identified	None identified	None
SINGLE POINT DIAMOND CUTTING TOOL INSERTS.	Flawless and chip-free cutting edge when magnified 400 times; Cutting radius from 0.1 to 0.5 mm, inclusive; and Cutting radius out-of-roundness < 0.002 mm TIR.	Diamond cutting tools	None identified	None identified	None
NON-NUMERICALLY CONTROLLED MACHINE TOOLS FOR GENERATING OPTICAL QUALITY SURFACE USING A SINGLE POINT CUTTING TOOL.	Slide positioning accuracy < .0005 mm/300 mm of travel; Bidirectional slide positioning repeatability < .00025 mm/300 mm of travel; Spindle run-out and camming < .0004 mm; Angular deviation < 2 sec. of arc; and Perpendicularity <.001 mm/300 mm travel.	None identified	None identified	None identified	WA IL Cat 2
NON-NUMERICALLY CONTROLLED FLY-CUTTING MACHINE TOOLS FOR GENERATING OPTICAL QUALITY SURFACES	Spindle run-out and camming < 0.0004 mm TIR; and Angular deviation of slide movement (yaw, pitch and roll) < 2 seconds of arc. TIR, over full travel.	None identified	None identified	None identified	WA IL Cat 2

(Continued)

Table 10.5-1. Production Equipment Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
MACHINE TOOLS SPECIALLY DESIGNED FOR CUTTING, GRINDING, HONING AND FINISHING OF HARDENED SPUR, HELICAL AND DOUBLE HELICAL GEARS.	Ability to produce hardened gears (Rc ≥ 40) with a pitch diameter > 1,250 mm and A face width of 15% of pitch diameter, or larger, finished to a quality of AGMA-14, or better (equivalent to ISO 1328 class 3).	None identified	None identified	None identified	WA IL Cat 2
HOT ISOSTATIC PRESSES	Chamber cavity whose inside diameter ≥ 406 mm; a A working pressure > 204 MPa; and Thermal environment >1,773 K;	None identified	None identified	None identified	WA IL Cat 2 NDUL 1.5
GRINDING, LAPPING AND HONING MACHINES FOR PRECISION BEARINGS	Capable of manufacturing precision bearings with radial run-out of 8 microinches, or better.	None identified	None identified	None identified	None
SOFTWARE FOR NCS/PCS THAT HAVE ≥ 4-AXES SIMULTANEOUS CONTOURING CONTROL.	The ability to control a machine tool having ≥ 4 axes, such that the movement on each axis can be simultaneously contour controlled.	None identified	None identified	None identified	WA IL Cat 2
SOFTWARE FOR NCS/PCS THAT HAVE REAL TIME PROCESSING OF DATA BY ADAPTIVE CONTROL WITH MORE THAN ONE PHYSICAL VARIABLE MEASURED AND PROCESSED BY MEANS OF A COMPUTING MODEL TO CHANGE ONE OR MORE MACHINING INSTRUCTIONS.	Ability to modify machining instructions, as a result of measuring > 1 variable, and Capable of changing one, or more machining instructions.	None identified	None identified	Software which allows real-time modification of the tool path, feed rate or spindle data.	WA IL Cat 2

SECTION 10.6—ROBOTICS

OVERVIEW

This subsection covers the technology for the general category of robots, controllers and end-effectors used in conjunction with other manufacturing equipment for the production or testing of critical hardware. Robots can essentially be separated into four distinct disciplines: the robot, the controller (computer), sensors (including cameras), and end effectors (the "gripper"). Robots have found a wide range of applications in manufacturing, including welders, sprayers, assemblers, loaders/unloaders, etc. They have also found use in handling hazardous or radioactive materials, transporting explosive weapons, and performing tasks in space.

Table 10.6-1. Robotics Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Control Regimes
ROBOTS (DESIGNED TO OPERATE IN EXPLOSIVE OR EMP ENVIRONMENTS), CONTROLLER AND END-EFFECTORS	Incorporating protection of hydraulic lines and Using fluids with flash points > 839 K	None identified	Machine tools, inspection equipment and all necessary equipment to manufacture sensors, etc.	None identified	NDUL 1.6(a)
ROBOTS DESIGNED FOR NUCLEAR ENVIRONMENTS	Designed to operate in a radiation environment greater than 5×10^5 rad (Si)	None identified	Machine tools, inspection equipment and all necessary equipment to manufacture sensors, etc.	None identified	WA IL Cat 2 NDUL 1.6(b)
ROBOTS DESIGNED FOR SPACE APPLICATIONS	Designed to operate at altitudes exceeding 150 miles.	None identified	Machine tools, inspection equipment and all necessary equipment to manufacture sensors, etc.	Operational software	WA IL Cat 2